

Remarks

Claims 1-5, 7-57, 73, 75-81, 96 and 98-121 are presently pending.

Claims 15, 22-57, 73, 75-81, 83-96, 101, 102, 107-111 and 113-121 have been withdrawn from further consideration.

The claims have been amended to clarify that the barrier layer consists essentially of nitrogen and silicon, and interfaces with the dielectric material. Support for the amendments is in the specification as filed. See, for example, the specification at pages 3-4, bridging paragraph ("...a nitridized silicon layer...*formed on an oxide layer* ...the nitride barrier layer ...*disposed adjacent an oxide layer*..."), at page 4, lines 21-25 ("The invention advantageously provides *an improved interface between a silicon nitride barrier layer and an underlying dielectric (oxide) layer*..."), and at page 7, lines 3-4 ("Referring to FIG. 3, the silicon layer 18 is then nitridized *to convert the silicon to silicon nitride (SiN_x)* 20...").

No new matter has been added with the amendments, which are intended to merely clarify language used in the claims and/or the subject matter claimed. The scope of the claims is intended to be the same after the amendment as it was before the amendment.

Rejection of Claims under 35 U.S.C. § 102(b) (Aronowitz)

The Examiner rejected Claims 1, 5, 7, 8, 18, 98-100, 103 and 106 under Section 102(b) as anticipated by Aronowitz (USP 6,087,229). This rejection is respectfully traversed.

The Examiner maintains that Aronowitz discloses a method of forming a nitride barrier layer as claimed, citing particularly to the intermediate silicon nitride layer (206) in **Fig. 2D**. The Examiner maintains that the intermediate silicon nitride layer 206 in **Fig. 2D** intrinsically (inherently) inhibits the passage of a dopant into the dielectric material.

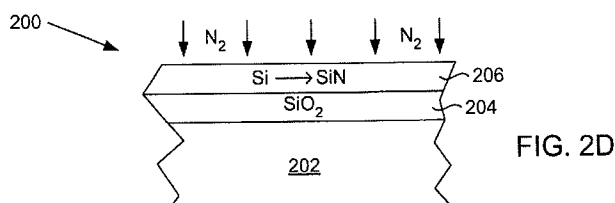
To constitute anticipation under Section 102, each and every element of a claimed invention must be found in a single reference. *Hybridism Inc. v. Monoclonal Antibodies, Inc.*, 802 F.2d 1367, 231 USPQ 81 (Fed. Cir. 1986); *Dalman v. Kimberly-Clark Corp.*, 713 F.2d 760, 771, 218 USPQ 781, 789 (Fed. Cir. 1983), cert. denied, 104 S.Ct. 1284, 224 USPQ 520 (1984); *In re Marshall*, 578 F.2d 301, 198 USPQ 344 (CCPA 1978).

That a certain result or characteristic may occur or be present in the prior art is not sufficient to establish the inherency of that result or characteristic. *SmithKline Beecham Corp. v. Apotex Corp.*, 74 USPQ2d 1396 (Fed. Cir. 2005); *Continental Can Company USA v. Monsanto Company*, 20 USPQ2d 1746 (Fed. Cir. 1991); *In re Oelrich*, 212 USPQ 323, 326 (CCPA 1981). In relying upon the theory of inherency, the Examiner must provide factual and technical grounds to support the determination that the allegedly inherent characteristic necessarily and inevitably results from the applied prior art. Inherency may not be established by probabilities or possibilities. The mere fact that a certain thing may result from a given set of circumstances is not sufficient. *In re Robertson*, 49 USPQ2d 1949, 1950-51 (Fed. Cir. 1999)

For the doctrine of inherency to apply it must be inevitable that Aronowitz' process to form the intermediate silicon nitride layer (206) in **Fig. 2D** necessarily results in a dopant (e.g., boron) diffusion barrier layer.

The intermediate SiN layer (206) (**Fig. 2D**) of Aronowitz is not an effective dopant (boron) diffusion barrier.

Fig. 2D (below) illustrates Aronowitz' formation of intermediate silicon nitride layer 206.



To form the intermediate silicon nitride layer **206** (**Fig. 2D**), Aronowitz merely implants nitrogen into the silicon layer. Aronowitz does not perform an anneal required to form the intermediate SiN material **206** into an effective boron diffusion barrier. Aronowitz describes the nitridization process at col. 5, line 57 to col. 6, line 34, as follows.

The thin silicon film 206 may then be nitridized, as shown in FIG. 2D. According to a preferred embodiment of the present invention, the wafer 200 may be introduced into a plasma reactor (not shown), such as one that is normally used for plasma etching of polysilicon. Suitable reactors can generate a plasma density and energy appropriate for the creation of ionic species having energies sufficient to break silicon-silicon bonds and penetrate the surface of the polysilicon film 206 without substantially damaging its structure. A relatively high density, such as about $10^{10}/\text{cm}^3$ to $10^{13}/\text{cm}^3$, and low energy, such as less than about 12 eV, preferably between about 5 and 10 eV, which can be separately controlled by the reactor, are preferred.

The LAM 9400SE is an example of such a reactor. Molecular nitrogen may be introduced into the reactor to form the plasma containing nitrogen species which have energies of less than about 20 eV, and which are sufficient to break silicon-silicon bonds so that these nitrogen (atomic and/or molecular) entities react at the surface of the polysilicon film 206 and within several atomic layers into the film producing a nitrogen-rich surface region in the polysilicon film 206.

...

For example, a LAM 9400SE reactor may be operated according to the following process parameters to achieve nitridization of a thin amorphous or poly silicon film deposited on an oxide, according to a preferred embodiment of the present invention: pressure of about 10 mtorr; N₂ flow rate of about 10 standard cubic centimeters per minute (sccm); TCP power of about 200 W; bias power of about 10 W; electrode temperature of about 60°C.; backside He pressure of about 8 torr; step time of about 10 minutes. Using these parameters, a plasma with about 10 eV nitrogen species may be produced resulting in nitridization of the thin silicon film to about 25 to 30 atomic percent.

The need for an anneal to form an effective 'dopant diffusion barrier layer' by nitridation of silicon material is evidenced, for example, by USP 6,410,968 (Powell et al.). See at col. 3, lines 8-43 below (emphasis added).

...A silicon-containing material is vapor deposited onto the surface of the wafer at block 203 from a silicon source. *The silicon-containing material is treated or processed using rapid thermal nitridation (RTN) in an NH₃ ambient at block 204 resulting in creation of the barrier layer. The temperature, anneal time and processing pressure are selected to obtain desired barrier layer characteristics.* ...

...FIG. 2B illustrates that *a suitable barrier layer may be formed at about 450 Torr and 850°C., over a processing time of 60 seconds with minimal oxidation of the underlying silicon substrate. It is noted that the 850°C. processing temperature is lower than the processing temperature (typically 950°C.) used to create barrier layers using conventional methods. In addition, the 60 seconds processing time is lower than the processing time used to create barrier layers using conventional methods (typically 45 minutes).* ...

Generally, conventional barrier layers are processed using temperature ranges of 700°C. to 1050°C., processing time of 10 seconds to 60 minutes, and processing pressure of 760 torr. Whereas, the barrier layer of the present invention is typically processed using temperature ranges of 500°C. to 900°C., processing time of 30 seconds to 5 minutes, and processing pressure of 450 torr. ...

In addition, **USP 7,465,617** (Ku et al.) at col. 7, lines 54-61, discloses that deposition or thickness of a SiN layer can be controlled '*so that the silicon nitride layer does not operate as a barrier*' (emphasis added).

When the silicon source gas is supplied to the reaction chamber having a nitrogen atmosphere, a thin silicon nitride layer may be deposited on the gate line patterns. However, because the flow rate and the supply period of the nitrogen source gas may be small, *the deposition or the thickness of the silicon nitride layer may be controlled so that the silicon nitride layer does not operate as a barrier*.

See also, **US 2008/0268634** (Yang) – at paragraphs [0007], [0021], which teaches implanting nitrogen and annealing the structure to form a boron diffusion barrier layer (at the interface between an Si layer and oxide layer).

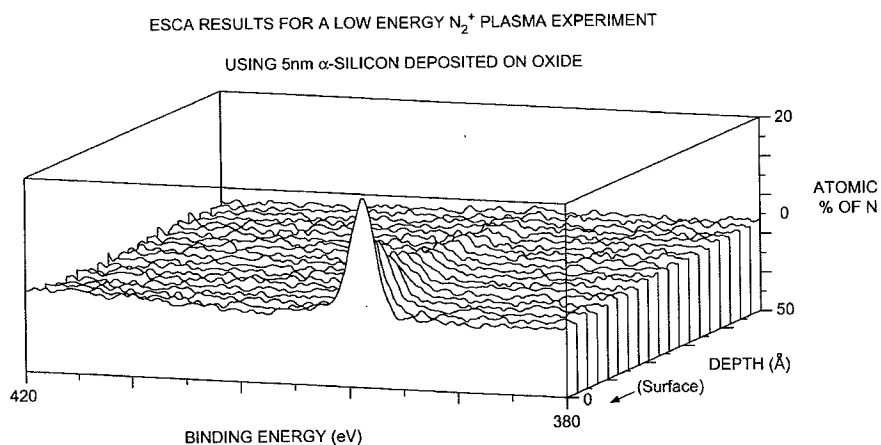
[0007] ...wherein the diffusion barrier layer is formed by implanting nitrogen into an interface region between the silicon layer and the buried oxide layer and annealing the structure to form the diffusion barrier layer between the buried oxide layer and the silicon layer.

[0021] ...*Diffusion barrier layer 214 is formed by implanting nitrogen into interface region 205 between silicon layer 206 and buried oxide layer 204 and annealing 212 (FIG. 7) structure 200 to form diffusion barrier layer 214 between buried oxide layer 204 and silicon layer 206.* As shown in FIGS. 6-7, oxygen 208 (FIG. 6) and nitrogen 210 (FIG. 7) are implanted into structure 200 following the formation of silicon layer 206. This oxygen/nitrogen ion beam implantation process is followed by a high temperature anneal 212 (FIG. 7) to create buried SiO₂ layer 204 and diffusion barrier layer 214, respectively. Diffusion barrier layer 214 effectively inhibits the diffusion of boron into regions underlying diffusion barrier layer 214.

Merely implanting nitrogen into silicon by Aronowitz' conditions does not inherently produce an effective boron barrier layer. As evidenced above, an anneal of the intermediate SiN layer **406 (Fig. 2D)** – e.g., a thermal anneal or oxygen anneal, would be required to form an effective dopant barrier.

The Examiner has provided no evidence or reasoning that Aronowitz' intermediate SiN layer **406 (Fig. 2D)** would necessarily and inevitably be an effective boron diffusion barrier.

Aronowitz teaches implanting nitrogen to produce a 'nitrogen-rich surface' resulting in a N-gradient going from a N-rich surface to little or no nitrogen at the interface with the oxide layer **204**. See the illustration of the N-gradient in **Fig. 3** (below) and the discussion at col. 6, lines 7-10 and 35-50 (emphasis added).

**FIG. 3**

...so that these nitrogen (atomic and/or molecular) entities react at the surface of the polysilicon film 206 and within several atomic layers into the film producing a nitrogen-rich surface region in the polysilicon film 206.

FIG. 3 shows a three-dimensional representation of the results an electron spectroscopic chemical analysis (ESCA) for a low energy nitrogen plasma implant using the parameters described above. The vertical axis represents atomic percent of nitrogen, and the side axis represents the depth of the thin silicon layer, starting from the surface and moving down. ...The results demonstrate that nitrogen is implanted according to a gradient from the surface of the silicon film, which is about 20 atomic percent nitrogen, to the interface with the oxide, which has very little or no nitrogen content. These results illustrate another useful feature of the present invention, which is that the nitrogen which hardens the dielectric layer is isolated from the underlying oxide and substrate layers and does not affect their performance.

Aronowitz' nitridization results in an intermediate structure (**Fig. 2D**) with a layer of silicon between the SiN surface layer and the underlying oxide.

The Si material situated between the oxide (SiO_2) layer and the SiN surface material will be essentially an undoped *polysilicon* that will have large depletion regions – not a dielectric. Aronowitz subsequently oxidizes the intermediate structure to transform the underlying Si material to a dielectric material – ie., SiO_2 or SiO_xN_y (and the SiN layer to SiO_xN_y). See col. 6, lines 51 to col. 7, line 3.

And, with 'little or no nitrogen' at the interface with the oxide layer **204** – and with 'the nitrogen that hardens the dielectric layer' isolated from the underlying oxide layer – the Si material that is in contact (interfacing) with the oxide layer cannot function as an effective dopant (boron) diffusion barrier.

The claims define Applicant's method as forming a *dopant diffusion barrier layer* 'consisting of nitrogen and silicon' (i.e., no oxygen) overlying and interfacing with a *dielectric material*.

By comparison, Aronowitz teaches forming an intermediate structure (**Fig. 2D**) composed of a silicon nitride layer over a silicon layer that interfaces with an oxide layer. Aronowitz' silicon nitride layer is not an effective or functional dopant diffusion barrier without further processing.

In sum, Aronowitz' method of forming the intermediate SiN structure (**Fig. 2D**) (**a**) lacks an anneal necessary to form a SiN dopant barrier layer, and (**b**) has a Si layer (*not* a SiN dopant barrier layer) interfacing with the oxide layer 204.

Aronowitz does not teach or suggest Applicant's method of forming a nitride barrier layer defined by a silicon nitride layer 'consisting of silicon and nitrogen' 'interfacing with' the dielectric material, which is an *effective dopant diffusion barrier*.

Accordingly, withdrawal of this rejection is respectfully requested.

Rejection of Claims under 35 U.S.C. § 103(a) (Aronowitz/Muralidhar)

The Examiner rejected Claims 2-4, 9-14, 16-17, 19-21, 104-105 and 112 as obvious over Aronowitz in view of Muralidhar (USP 6,297,095). This rejection is respectfully traversed.

The Examiner maintains that Aronowitz is "silent" regarding the 'claimed conditions' and cites to Muralidhar for disclosing various process parameters, as defined in the claims, citing to Figs. 23-25 and col. 16, lines 19-36, for forming a silicon nitride "barrier" layer **106/107**. The Examiner maintains that it would have been obvious to utilize the processing conditions described by Muralidhar in the method of Aronowitz to "optimize the process."

At col. 16, lines 19-36, Muralidhar discloses processing conditions for forming a thin, silicon nitride encapsulation layer over the surface of silicon nanoclusters by flowing a nitriding ambient (e.g. ammonia) over the silicon nanoclusters at high temperature (700-1000°C). See below and **Fig. 23** (emphasis added).

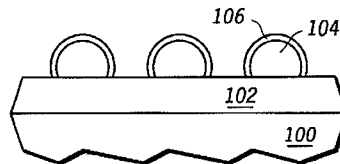


FIG.23

Further processing steps can be performed in order to limit the oxidation or other degradation of the nanoclusters due to ambient exposure. **FIG. 23** illustrates the nanocluster structures of FIG. 22 following an encapsulation step. The encapsulation step forms an encapsulation layer 106 on each of the nanoclusters 104. Such an encapsulation layer 106 may be formed of silicon nitride. Silicon nitride may be formed on the surface of the nanoclusters 104 by exposing the nanoclusters 104 to a nitriding ambient at high temperature. Such an ambient may include ammonia, nitrous oxide, or other nitrogen-containing compounds that are reactive to silicon in a manner that can be controlled. In one embodiment, a thin layer of nitride is formed on the nanoclusters by flowing ammonia, without other reactants, over the nanoclusters. The conditions under which the ammonia may be flowed may include a temperature within a typical range of 700-1000 degrees Celsius and a pressure within a typical range of 1-760 Torr.

At col. 17, lines 13-27, Muralidhar describes forming a nitride layer 107 by deposition using CVD processing. See below and **Fig. 25** (emphasis added).

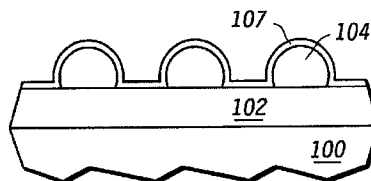


FIG.25

In other embodiments, a protecting nitride layer may be deposited rather than grown on individual nanoclusters. **FIG. 25** illustrates the nanocluster structures as shown in FIG. 22 following a step where a thin nitride layer 107 is deposited. The nitride layer 107 may be deposited using CVD operations that utilize ammonia and dichlorosilane. Such CVD operations may be performed using LPCVD or UHVCVD techniques. ...

Muralidhar's nitride layers **106/107** are only taught as a barrier to oxygen – not as a dopant barrier. This is stated by Muralidhar at col. 17, lines 1-12 and 28-40 (emphasis added).

...By including the encapsulation layer **106**, oxidation or other degradation *due to oxidizing ambient exposure* of the nanoclusters **104** can be reduced or eliminated. As such, the diameter of the nanoclusters **104** is maintained, and no uncontrolled increase in the underlying tunnel dielectric occurs.

...
The thin nitride layer **107** illustrated in **FIG. 25** forms a barrier to oxygen such that both the nanoclusters **104** and the underlying semiconductor substrate **100** below the tunnel dielectric layer **102** are protected from oxidation. As such, the potential for an increase in the thickness of the tunnel dielectric layer **102** is reduced.

There is no teaching in Muralidhar of forming a dopant barrier.

Moreover, one skilled in the art reading Aronowitz's disclosure would not modify the processing parameters as proposed by the Examiner.

First of all, Aronowitz addresses conventional methods for diffusing nitrogen into a gate oxide in the background section of the disclosure at col. 2, lines 9-32. Aronowitz specifically addresses drawbacks of conventional processes that expose a gate oxide to ammonia at high temperature (about 900°C) to incorporate nitrogen into the gate oxide – which introduce electron traps into the dielectric and increase the fabrication process thermal budget.

See Aronowitz at col. 2, lines 9-32 (emphasis added).

Conventional methods for hardening gate oxides have involved diffusing nitrogen into a gate oxide after its formation. In this process, the gate oxide is thermally grown on a single crystal silicon substrate. Next, the gate oxide is exposed to an atmosphere containing nitrous oxide, nitric oxide, ammonia or other nitrogen source at a high temperature (about 900°C.) which results in nitrogen incorporation into the gate oxide. The resulting increased concentration of nitrogen containing species in the gate oxide prevents boron diffusion into the silicon substrate, hot electron degradation and improves the breakdown resistance of the gate oxide.

Unfortunately, hardening through nitrogen incorporation through the oxidation process has some drawbacks. Among these problems are that the high temperature treatment involved in gate oxide hardening by nitrogen diffusion cuts into the fabrication process' thermal budget. In addition, hardening with an ammonia anneal introduces electron traps into the dielectric. Furthermore, because the nitrogen tends to localize at the substrate-gate oxide interface, conventional hardening does reduce boron diffusion from the gate oxide to the silicon substrate, but fails to prevent boron diffusion into the gate oxide from a doped polysilicon gate electrode. This is important since the properties of the gate oxide may be adversely affected by creation of traps in oxide by dopants such as boron.

Secondly, Aronowitz teaches a low energy nitrogen plasma implantation to nitridize the polysilicon film – and explicitly teaches specific processing conditions for implanting the nitrogen. The result is a decreasing nitrogen gradient from the surface of the silicon film to the underlying oxide interface. See at col. 6, lines 23-37 (emphasis added).

For example, a LAM 9400SE reactor may be operated according to the following process parameters to achieve nitridization of a thin amorphous or poly silicon film deposited on an oxide, according to a preferred embodiment of the present invention: *pressure of about 10 mtorr; N₂ flow rate of about 10 standard cubic centimeters per minute (sccm); TCP power of about 200 W; bias power of about 10 W; electrode temperature of about 60°C.; backside He pressure of about 8 torr; step time of about 10 minutes. Using these parameters, a plasma with about 10 eV nitrogen species may be produced resulting in nitridization of the thin silicon film to about 25 to 30 atomic percent.*

FIG. 3 shows a three-dimensional representation of the results an electron spectroscopic chemical analysis (ESCA) *for a low energy nitrogen plasma implant using the parameters described above.* The vertical axis represents atomic percent of nitrogen, and the side axis represents the depth of the thin silicon layer, starting from the surface and moving down. The horizontal axis represents the binding energy of core electrons. *The results demonstrate that nitrogen is implanted according to a gradient from the surface of the silicon film, which is about 20 atomic percent nitrogen, to the interface with the oxide, which has very little or no nitrogen content.* These results illustrate another useful feature of the present invention, which is that the nitrogen which hardens the dielectric layer is isolated from the underlying oxide and substrate layers and does not affect their performance.

Clearly, one skilled in the art reading Aronowitz's disclosure including the background section which addresses the disadvantages of a high temperature ammonia anneal, would not modify the processing parameters of Aronowitz as proposed by the Examiner.

Accordingly, the Examiner is respectfully requested to reconsider and then withdraw this basis of rejection of the claims.

Extension of Term.

The proceedings herein are for a patent application and the provisions of 37 CFR § 1.136 apply. Applicant believes that a one-month extension of term is required. Please charge the required fee (large entity) to Account No. 23-2053. If an additional extension is required, please consider this a petition therefor, and charge the required fee to Account No. 23-2053.

It is submitted that the present claims are in condition for allowance, and notification to that effect is respectfully requested.

Respectfully submitted,



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Dated: July 30, 2010

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